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Maximizing profit for vehicle routing under time and weight constraints

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ABSTRACT

Utilizing an empty backhaul vehicle on its way back to its domicile after a normal delivery trip has attracted many logistics carriers and third party logistics companies in the current revenue-hungry economy. In this paper, a backhaul vehicle routing and delivery scheduling problem is studied with the objective of maximizing the total business profit that the vehicle generates during its backhaul trip. The problem has two constraints: the *time constraint* for the entire backhaul trip and the *capacity constraint* of the vehicle. It also has two integral parts, vehicle routing and delivery scheduling. An analytical model is developed for this problem, which turned out to be NP-hard to solve due to its complexity. Therefore, the model is decomposed into two parts: finding feasible routes and generating the best delivery schedule for a given route. A heuristic solution is developed to solve the model, in which a genetic based algorithm is used to find the best known feasible route and a linear programming model is used to find the best delivery schedule for a given route. The two solution parts are integrated seamlessly and the best solution is found after iterating through the routes in search for improvement. Numerical study of various sizes of problems has demonstrated that relatively large size of problems could be solved with good solution quality in a reasonable time which is acceptable in real world practice. Third party logistics or other companies could use the solution method provided in this study to utilize their unused vehicle capacity in certain time periods, such as during a backhaul trip, which might be otherwise ignored.

1. Introduction

In the current globalized and distributed economic environment, companies are more interconnected and rely more on transportation for their business. The competition among logistics companies has become more and more intensive. Customers of logistics companies have high expectation of service quality which often requires on-time delivery within a small delivery time window and with short notice. One way to gain the edge in such a competitive market is to increase the vehicle utilization, especially during the backhaul trip after a dedicated delivery. After reaching its destination, a vehicle is usually empty during the backhaul trip to its domicile. To increase the utilization, an empty backhaul vehicle should be used to pick up additional delivery business on its way back. A backhaul vehicle is usually required to return to its domicile within a certain time period so that the normal transportation schedule will not be disrupted. There could be more than one delivery service request that can be satisfied using the backhaul vehicle. The service requests could be for truckload (TL) service or less-than-truckload (LTL) service. The profit of each delivery service depends on the delivery quantity, delivery distance, and detour travel distance needed for some other deliveries. The overall profit will depend on the selection of delivery service requests and the routing sequence. A vehicle also has limitation on its delivery capacity, which is another factor that may influence the choices of customers and subsequently, the vehicle routing and overall profit.

Therefore, the problem here is to decide which delivery service requests should be fulfilled and which traveling route should be taken in order to maximize the total profit the backhaul vehicle can generate given time and weight constraints. The problem presented here is a very common problem in the transportation industry. However, to the best of authors' knowledge, there has been little study about it in the literature. In this paper, we will discuss the problem and present an efficient algorithm to solve it.

The problem described above belongs to the vehicle routing problem (VRP), which could be simply defined as the problem of designing least-cost delivery routes from a depot to a set of geographically scattered customers, subject to site constraints (Laporte 2009). It was firstly proposed by Dantzig and Ramser (1959) and has been deeply and broadly discussed for the last 50 years. For a comprehensive review and their variants on VRP, the readers are referred to Laporte (2009), Toth and Vigo (2002), and Golden, Raghavan, and Wasil (2008).

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The problem presented in this paper may fall into the category of pickup and delivery problems (PDP), in which vehicles start from one depot, pickup and deliver all products, and then return to the same depot. PDP has been studied by a number of researchers in the past including Min (1989), Mosheiov (1994), Nagy and Salhi (1998, 2005), Salhi and Nagy (1999), Gendreau et al. (1999), Dethloff (2001, 2002), Alfredo Tang Montané and Galvao (2002, 2006), Süral and Bookbinder (2003), Wasner and Zäphel (2004), Halskausr et al. (2007) and Hoff et al. (2009). However, in these studies, all the pickups have to be delivered to the same location – the depot. Recently Gribkovskaia et al. (2008) have studied a single vehicle routing problem with mandatory deliveries and selective pickups, in which all deliveries must be performed, but pickups are optional based on the revenue associated with each pickup vertex. Nevertheless, all pickups have to be transported to depot as well. Wang and Chen (2013) studied a flexible delivery and pickup problem with time windows in which all the pickups are delivered to the same location and one customer is visited exactly once by one vehicle for one service.

According to the categories defined by Berbeglia et al. (2010), PDP can be classified into three different groups: many-to-many problems, one-to-many-to-one problems and one-to-one problems. Ting and Liao (2013) summarized the classification of PDP variants.

In a one-to-one problem, each customer's delivery request has its own given origin and destination instead of the common depot. Pang et al. (2011) studied one of its applications for shipping cargoes, and Heilporn et al. (2011) studied another application called dial-a-ride system. The problem can be further classified as a static one if all the necessary data are known before constructing routes, or a dynamic one if some of the data are only revealed or updated in operations. Berbeglia et al. (2010) provided a general framework for dynamic one-to-one PDPs. Our problem is a variant of static one-to-one pickup and delivery problem. However, the vehicle is not required to visit every vertex and the objective function is to maximize the profit on the route. Ting and Liao (2013) presented a novel problem formulation of selective pickup and delivery problem which relaxes the requirement for visiting all pickup nodes and searches for a minimum-cost route for a vehicle with capacity constraint. The relaxation is very similar to our problem. However the vehicle in the problem is still required to make stops at all delivery nodes, which is a many-to-many, but not one-to-one problem.

Hernández-Pérez and Salazar-González (2009) studied the multi-commodity one-to-one pickup-and-delivery traveling salesman problem in which the demand and the cost for delivering different commodities are known, and the vehicle has a limited capacity. Each customer must be visited exactly once and the objective is to minimize the total cost.

A special case of one-to-one problem is the courier delivery problem (CDP), a variant of the vehicle routing problem with time windows (VRPTW) involving uncertain service times and probabilistic customers. The problem has been studied and solved by various researchers including Savelsbergh and Goetschalckx (1995), Beasley and Christofides (1997), Malandraki et al. (2001), Zhong et al. (2007), Gröer et al. (2009). However, the aim of the problem is to find maximum customer coverage and optimal delivery consistency.

Among all the work we have reviewed in literature, little work has been done on the problem we have described earlier, in which the vehicle could pick up and drop off between any two locations based on customer demand and transport heterogeneous products on the same vehicle under certain time and weight constraints. The objective of our problem is to select the best customer set and route that will maximize the total profit. We are going to discuss this problem in detail in next section.

2. Problem and model formulation

We assume that the time required for a backhaul vehicle to return to the origin from its final delivery destination is given. This time constraint can be translated to the maximum distance the vehicle can travel for its entire backhaul trip. We assume that all delivery demands from potential customers are known. We also assume that customers only pay for the delivery based on the weight and the Euclidean distance between its pickup and drop-off locations, though the vehicle may detour between the two locations for other business. The challenge in this problem is to determine which customers' deliveries should be selected in the trip and which route should be taken to get back to the origin without violating the time or distance constraint. Since a customer only pays for the delivery based on the Euclidean distance between its pickup and drop-off locations, any extra detour distance for that customer will only incur extra cost, although such detour may be necessary for the business.

For example, as demonstrated in Fig. 1, a backhaul vehicle is supposed to travel back from A to B. There are eight different locations in figure. Each of the locations could be a pickup or drop-off location for a potential customer. One feasible schedule is to select three delivery requests of A to 5, 5 to B and 7 to B and the corresponding route is (A, 5, 7, B) within the distance limit. The customer of the second delivery request only pays for the cost from 5 to B although the vehicle is detoured for the third pickup. Such a detour will incur extra cost which needs to be considered when calculating the extra profit from the third delivery business.

The problem in our study is very complex because the number of feasible routes and the number of delivery selections are huge, which can be demonstrated by the following example. There are only two locations between A and B in a four-location problem. The routing distance constraint is relaxed so that the worst scenario of computation complexity can be explored. There exist delivery requests between any two locations as showed in Part (1) of Fig. 2 and each location can only be visited at most once. All possible routes are shown in the figure. Parts (2) and (3) show the routes with both locations visited, Parts (4) and (5) show the routes with only one location visited and Part (6) shows that the vehicle goes directly from A to B. For the route $A \rightarrow 1 \rightarrow 2 \rightarrow B$, as shown in Part (2), there are $C_4^2 = 6$ possible delivery requests marked by dash lines, where C_n^2 is the number of different ways of choosing ordered pair of 2 locations out of n locations in the route. Out of 6 possible delivery requests along the route, zero or up to six requests could be selected if the vehicle's capacity is allowed. So, there are $C_6^0 + C_6^1 \cdots + C_6^6 = 2^6 = 64$ ways to select delivery requests in total in this specific route. Therefore, for this four-location problem between A and B, the number of feasible configurations for the route is $P_2^2 \times 2^{C_4^2} + P_2^1 \times 2^{C_3^2} + P_2^0 \times 2^{C_2^2} = 146$ in which P_n^r means the permutation of selecting a route with r out of n locations between A and B. For an n-location problem, in

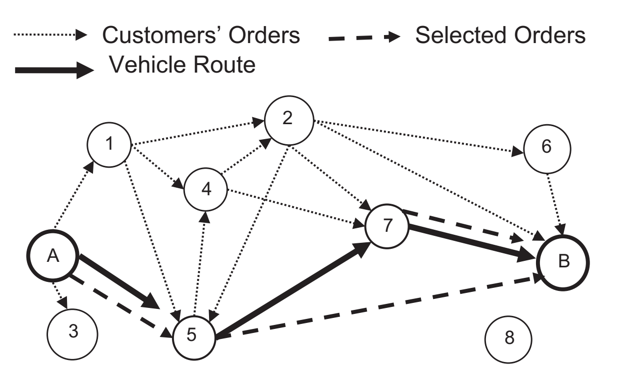

Fig. 1. Backhaul vehicle routing example.

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